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Real World Applications of Risk Assessment for Drinking Water Security

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Overview

- Motivation
- Characteristics of Water Distribution Systems
- The TEVA Research Program
- TEVA Risk Assessment Methodology
  - Predicting Exposure
  - Estimating Health Impacts
  - Incorporating Uncertainty
- Research Needs

Motivation

- Quantitative risk assessment in water distribution systems can help answer many of the questions being asked by water security researchers:
  - What are the likely public health consequences of contamination events in drinking water?
  - What detection strategies will work and how effective are they?
  - What is the best system-specific design for a mitigation technology?
  - How does this approach compare to another strategy?

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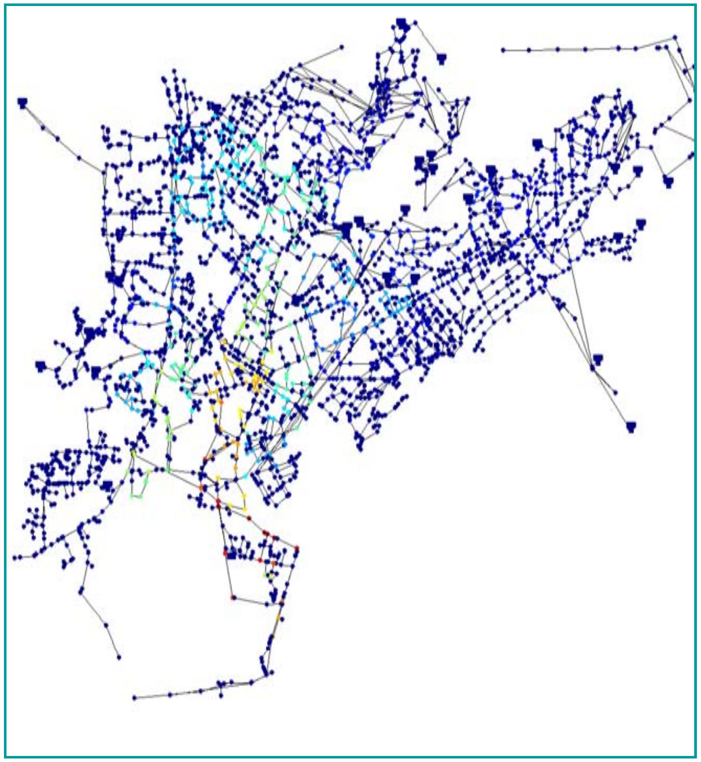
Characteristics of Water Distribution Systems

- **Topology**
  - Spatially distributed infrastructure over hundreds of miles
- **Flow patterns**
  - Looped
  - Multiple flow paths
  - Driven by customer demands
  - Subject to operational constraints



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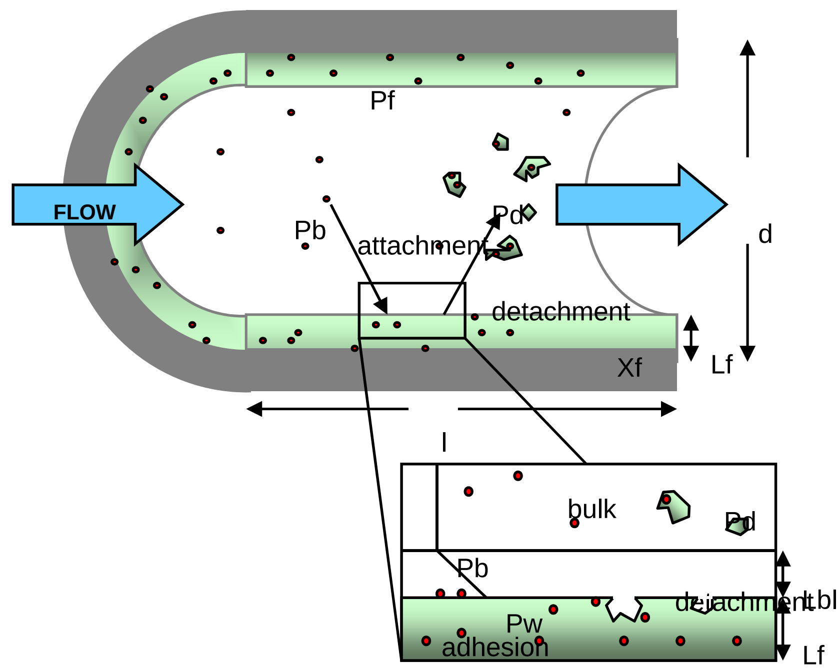
Characteristics of Water Distribution Systems

- **Contaminant fate and transport**
  - Mixing at junctions
  - Interaction with substances in the bulk water
    - Disinfectant residual
    - Natural organic matter
  - Reaction with pipe walls
    - Adsorption/desorption to pipe materials and corrosion products
    - Attachment to biofilms



The TEVA Research Program

Research Team

- EPA/NHSRC/WIPD
- EPA/NRMRL/WSWRD
- University of Cincinnati
- Argonne National Laboratory
- Sandia National Laboratories

Partners

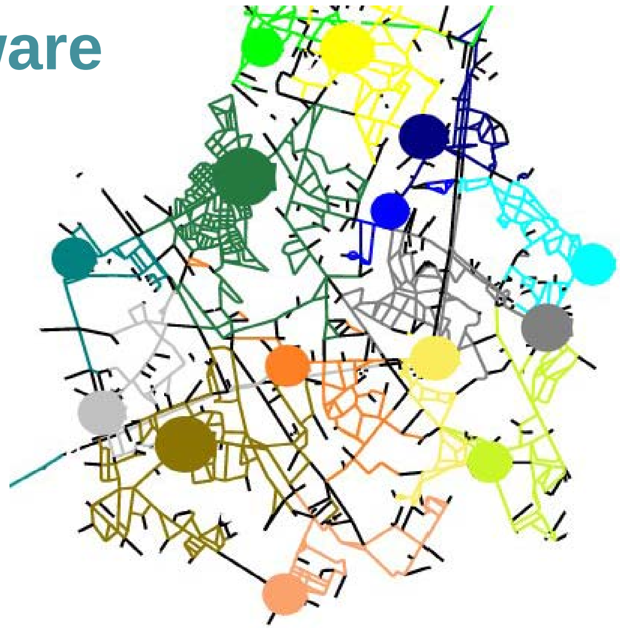
- American Water Works Association (AWWA)
- 9 Partner Utilities
- 22 Utilities

Objective

- To develop quantitative methods to assess risk and to evaluate risk mitigation strategies for drinking water distribution systems.

http://www.epa.gov/nhsrc/water/teva.html

TEVA-SPOT Sensor Placement Software

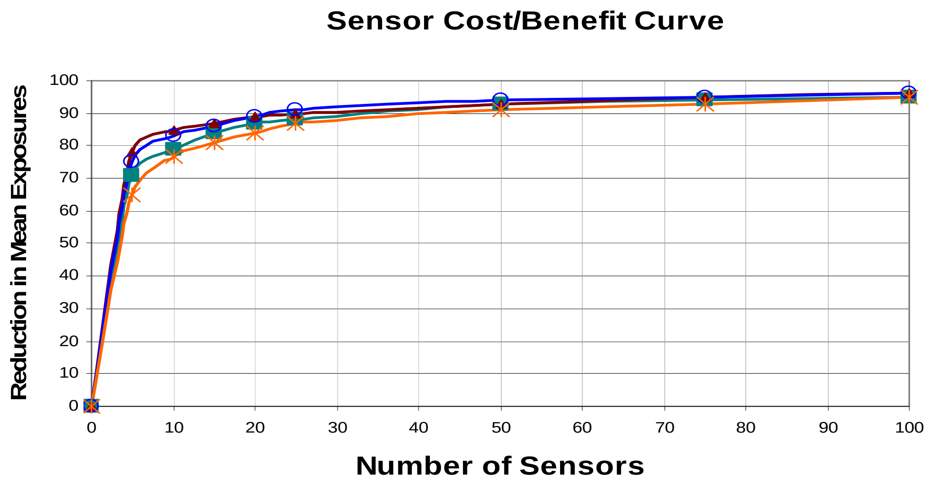


How TEVA-SPOT works:

- User specifies design basis threat
- User provides network model
- Selects optimal design for sensor network throughout distribution system

TEVA-SPOT status:

- Tested on data from nine partner utilities
- Designs have been or will be implemented at several utilities
- Used to design sensor network for WSI pilot utility
- Will be available to public on EPA website



CANARY Event Detection Software

How CANARY works:

•Analyzes water quality in real-time

•Differentiates between background variability and anomalous events

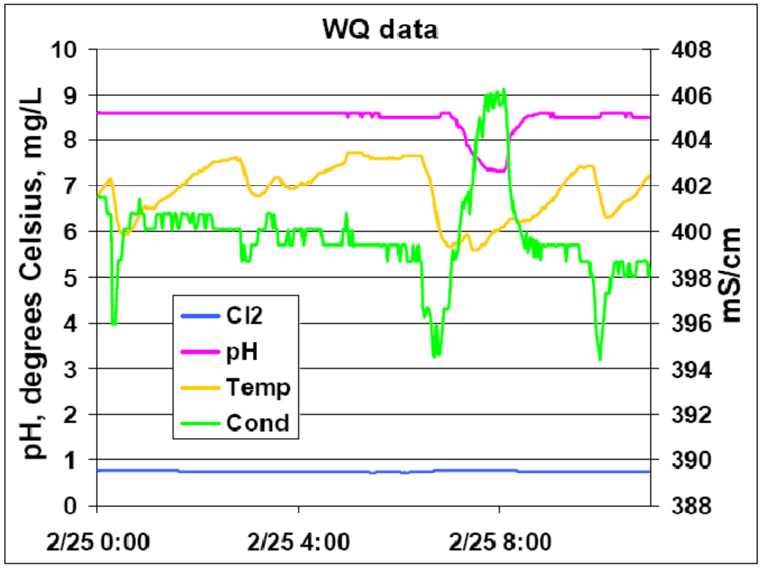
CANARY status:

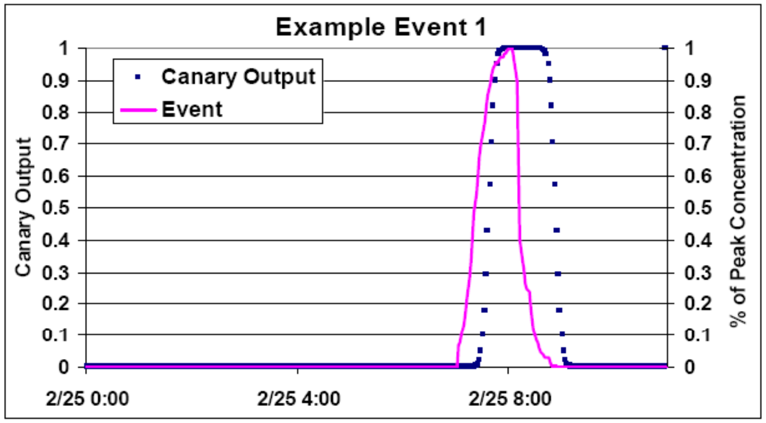
•Tested on data from two partner utilities

•Tested on data from T&E sensor experiments

•Operating at WSI pilot utility since July 2007

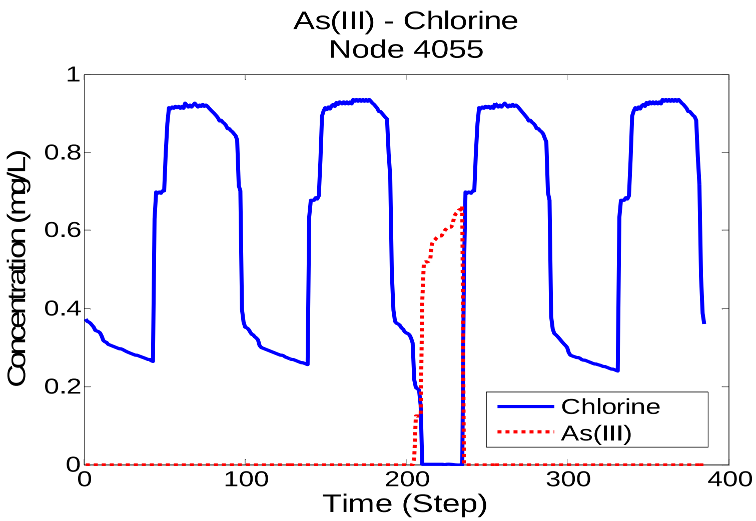
•Will be available to public on EPA website



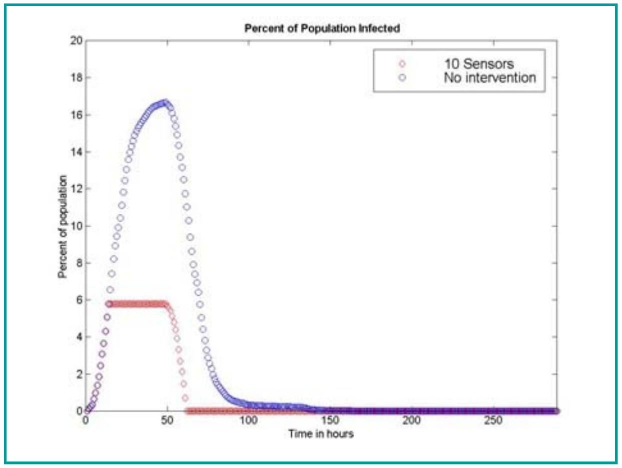


EPANET-MSX (Multi-Species eXtension)

- EPANET-MSX is an extension to EPANET that allows for the modeling of multiple interacting contaminants in drinking water pipe networks.
- EPANET-MSX is both a command-line executable, and an application programming interface (API), which is used in conjunction with the EPANET Toolkit
- Software and User’s Manual available on EPANET website



TEVA Risk Assessment Methodology



- Quantitative risk assessment underlies the TEVA software tools
- Public health impacts and economic impacts are calculated in order to measure the reduction in impacts (or benefits) of mitigation technologies
- Extensions to modeling tools are needed for accurate risk assessments

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TEVA methodology to estimate public health impacts from consumption of contaminated water

Hydraulic Model

EPANET predicts

- Velocity, $V(x,t)$
- Pressure, $P(x,t)$
- Concentration, $B(x,t)$

Disease Transmission Model

Applied at each node

- Susceptible, $S(x_n,t)$
- Infected, $I(x_n,t)$
- Diseased, $D(x_n,t)$
- Fatalities, $F(x_n,t)$

Exposure Model

Concentration $B(x,t) \longrightarrow$ Dose $D(x,t) \longrightarrow$ Response $R(x,t) \longrightarrow$ Infectivity Rate $\lambda(x,t)$

Hydraulic Model

Hydraulic Model

EPANET predicts
- Velocity, $V(x,t)$
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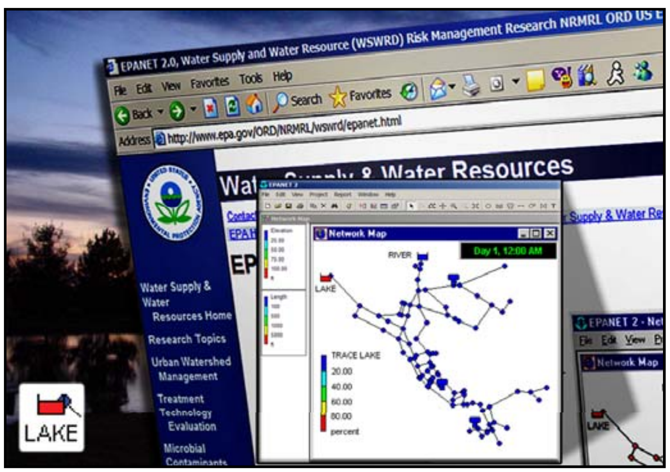

- Configured for each water utility
- Reflects operational and user demand patterns
- EPANET
- EPANET-MSX

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Exposure Model

Exposure Model

Concentration $B(x,t) \longrightarrow$ Dose $D(x,t) \longrightarrow$ Response $R(x,t) \longrightarrow$ Infectivity Rate λ

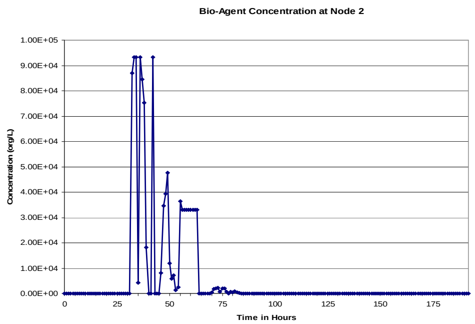
The dose received by an individual is the summed product of the contaminant concentration and the water consumed:

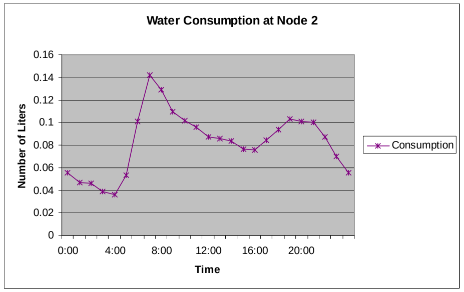
$\mathrm{Dose}(x_n) = \Sigma_i \{B(x_n,t_i) \times W_c(x_n,t_i)\}$ where

$B(x_n,t_i)$ = Concentration of Cont.

$W_c(x_n,t_i)$ = Water Consumed

$= (1/12) \times D(x_n,t_i)/\mathrm{Avg}\{D(x_n,t_i)\}$





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Dynamic Disease Transmission Model

Disease Transmission Model

Applied at each node
- Susceptible, $S(x_n,t)$
- Infected, $I(x_n,t)$
- Diseased, $D(x_n,t)$
- Fatalities, $F(x_n,t)$

$$\frac{dS}{dt} = \gamma R(t) - (\lambda(B,t)+\mu)S(t) \quad (1)$$

$$\frac{dI}{dt} = \lambda(B,t)S(t) - (\sigma+\mu)I(t) \quad (2)$$

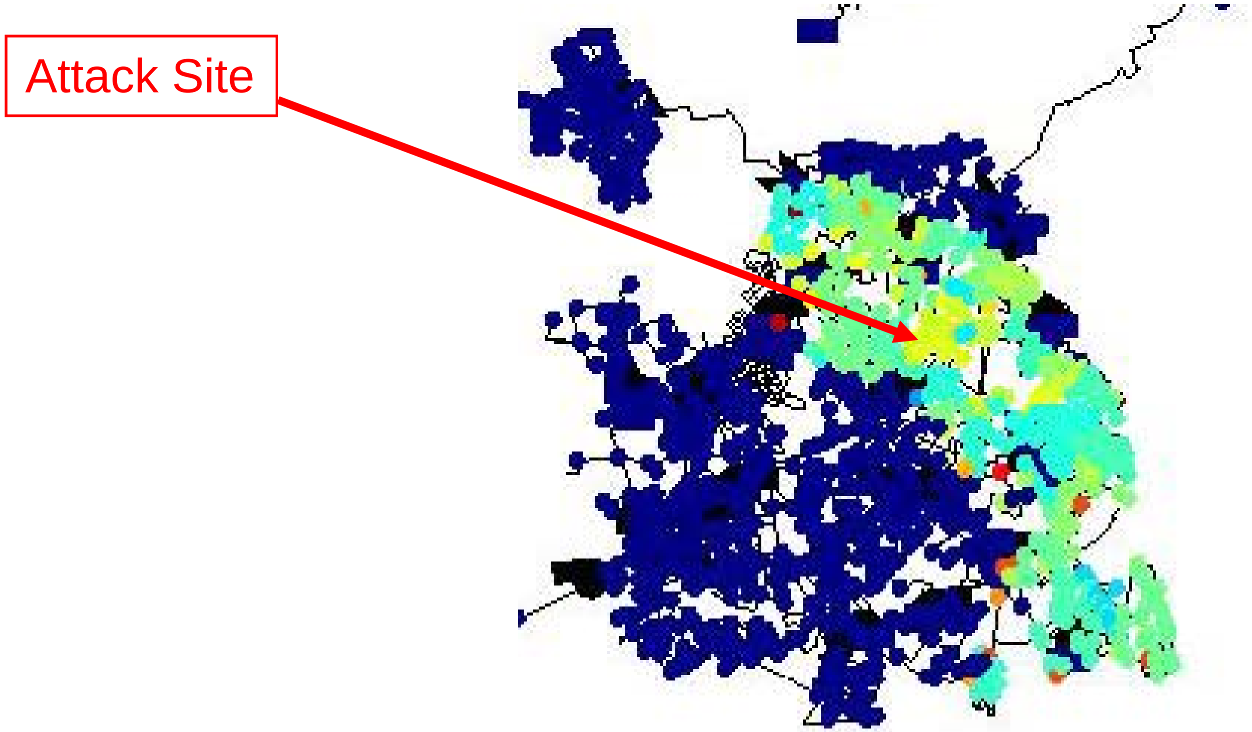
$$\frac{dD}{dt} = \sigma I(t) - (\alpha+\mu+v)D(t) \quad (3)$$

$$\frac{dR}{dt} = vD(t) - (\mu+\gamma)R(t) \quad (4)$$

$$\frac{dF}{dt} = \alpha D(t) \quad (5)$$

where $S(t)$ is the number of susceptible persons at time t, $I(t)$ the number of infected, $D(t)$ the number of diseased (infected and symptomatic), $R(t)$ the number of recovered and immune, $F(t)$ the number of fatalities due to disease, and $B(t)$ the population of organisms.

Network-wide Consequences



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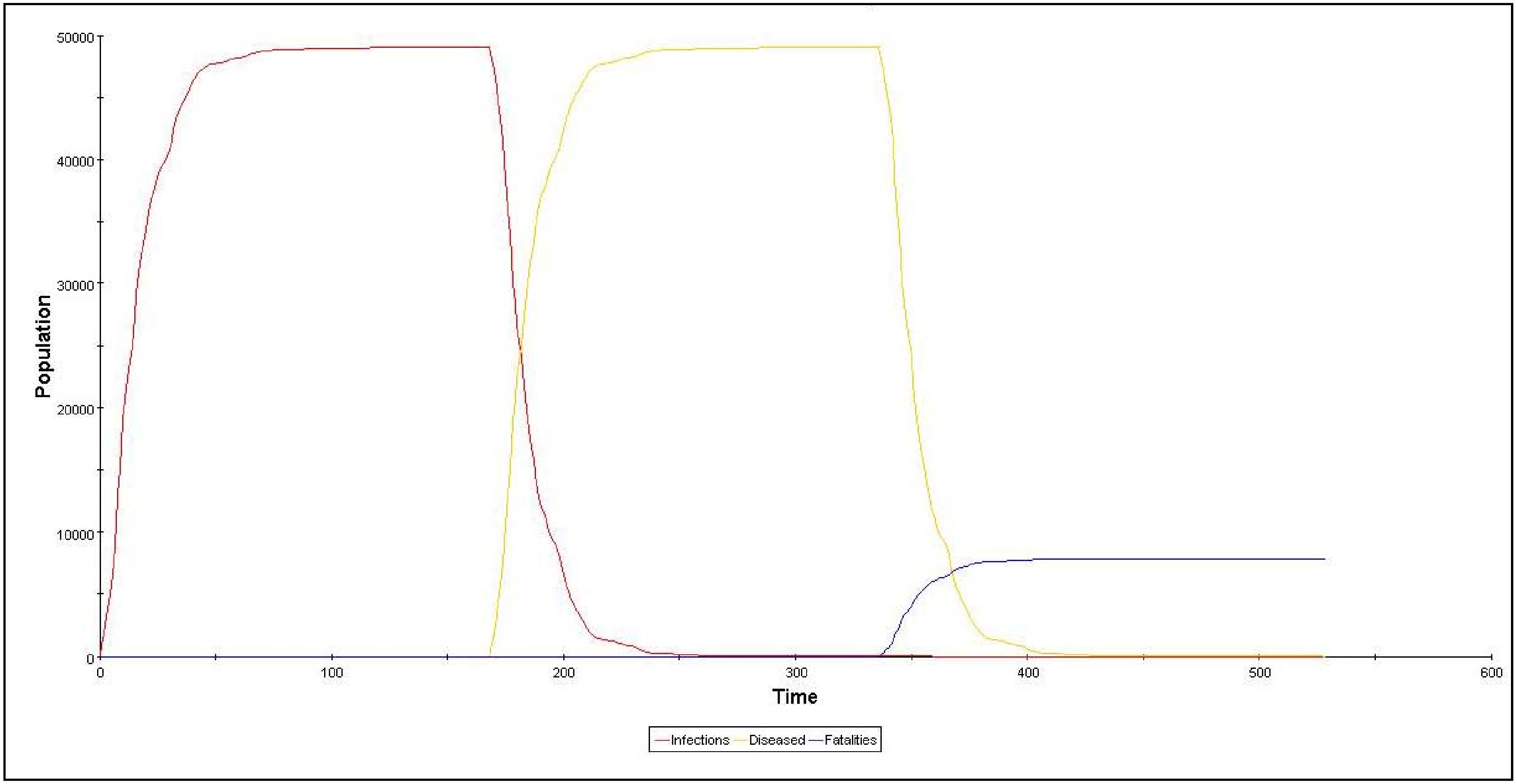
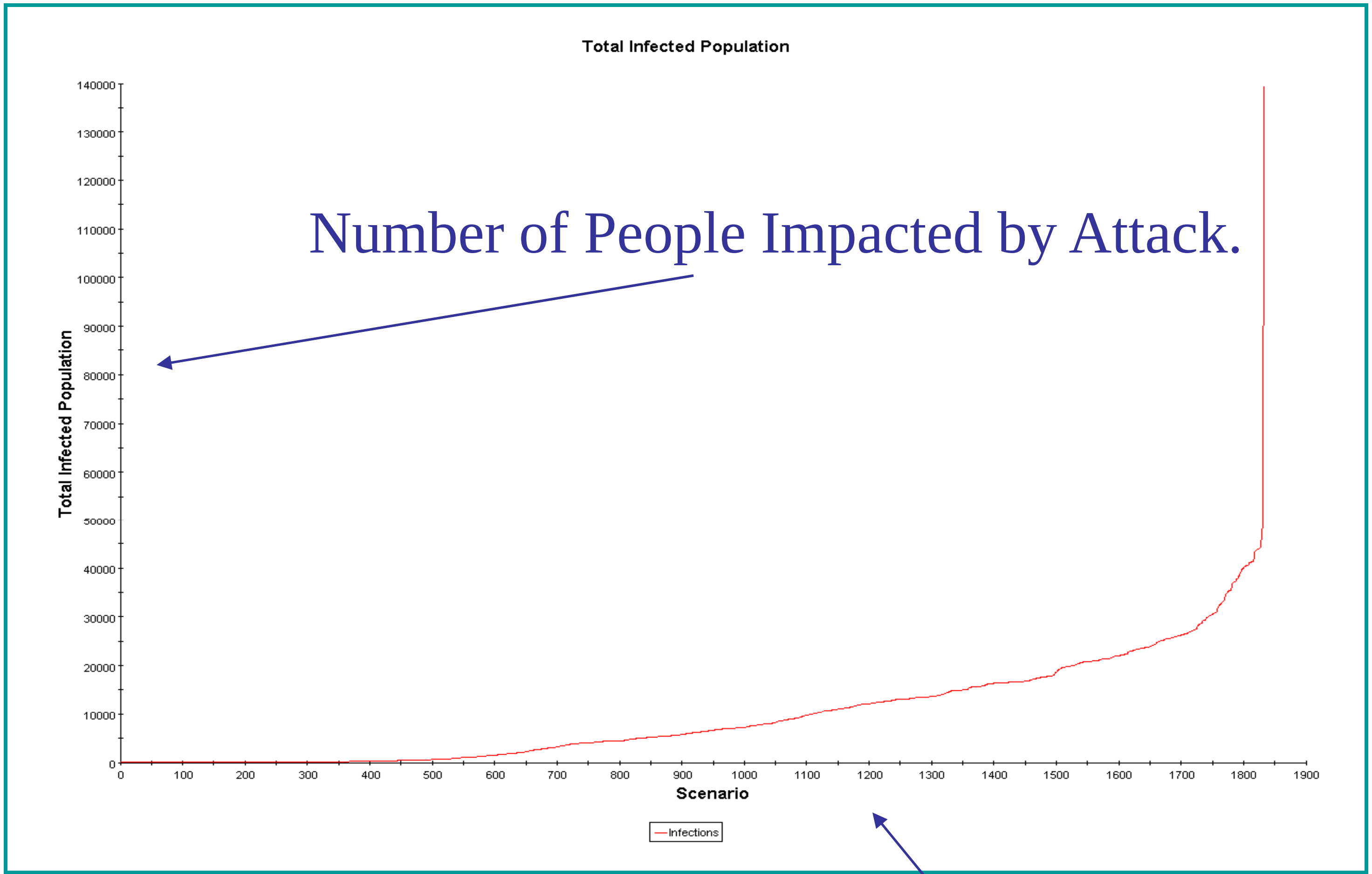
Network-wide Population Infected, Symptomatic, and Fatally Impacted Over Time



Total Impact Statistics Over Many Scenarios: Effect of varying Location



Number of People Impacted by Attack.

All attack scenarios are listed here!

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Uncertainty

- Not enough data to deterministically predict:
  - **Contamination scenarios:**
    - Attack location
    - Time of day and length of attack
    - Type of contaminant
    - Amount and concentration of contaminant
  - **Customer behavior:**
    - Timing and amount of water consumed
    - Movement through the spatial network (work, home, school, etc.)

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Research Needs

- Contaminant fate and transport in drinking water
  - Disinfection reactions
  - Adsorption/desorption mechanics
  - Attachment to biofilms
- Incorporation of uncertainty into models
  - Monte Carlo extension to EPANET
- Improved exposure models
  - Variability in population risk
  - Realistic customer behavior

THANK YOU!

- For more information:

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